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A Generalized Geologic Map of Mars

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A geologic map of Mars has been constructed largely on the basis of photographic evidence. Four classes of units are recognized: (1) primitive cratered terrain, (2) sparsely cratered volcanic eolian plains, (3) circular radially symmetric volcanic constructs such as shield volcanoes, domes, and craters, and (4) tectonic erosional units such as chaotic and channel deposits. Grabens are the main structural features; compressional and strike slip features are almost completely absent. Most grabens are part of a set radial to the main volcanic area, Tharsis.

A generalized geologic map of Mars has been constructed largely on the basis of differences in the topography of the surface. The success with which the geology can be deduced from surface topography depends on how distinctively the original topography of a feature reflects its mode of origin and the extent to which subsequent modification can be recognized and assessed. We are fortunate in having a number of topographic features on Mars whose forms are highly diagnostic of their origin. Of particular note are the shield volcanoes and lava plains. In some areas the original features have been considerably modified by subsequent erosional and tectonic processes. These have not, however, resulted in homogenization of the planet's surface but rather have emphasized its variegated character by leaving a characteristic imprint in specific areas. The topography of the planet therefore lends itself well to remote geologic interpretation.

The map (Figure 1) is an outgrowth of an earlier version of the equatorial belt [*McCauley et al.*, 1972]. The techniques and conventions used are similar to those used for the moon and have been fully described elsewhere [*Wilhelms*, 1972]. The surface has been divided into several units, each of which has a specific range of topographic characteristics. In the map explanation (Figure 2) the units are arranged according to their age as inferred from superposition and transection relations, crater counts, and so forth. The map also provides a generalized indication of tectonic deformation. Most of the units represent materials of a specific origin deposited within a restricted period of time. Other units, such as the chaotic and knobby materials, are not strictly geologic deposits but are modifications of preexisting materials. The modifications, however, have been so drastic as to, in effect, create new geologic units, and they are mapped as such.

For this early version of the map, data from the various spectral instruments have been largely ignored because of the difficulty in obtaining the data in a form readily correlatable with the visual image. However, we would not expect that, at the scale at which the map is depicted here, the spectral data would significantly affect delineation of the various units. The scale was dictated by journal format and should not be taken as indicative of a present level of knowledge. The map is a very coarse generalization of the information available. A more detailed map that will do justice to the wealth of information in the Mariner photography will be published in the not too distant future.

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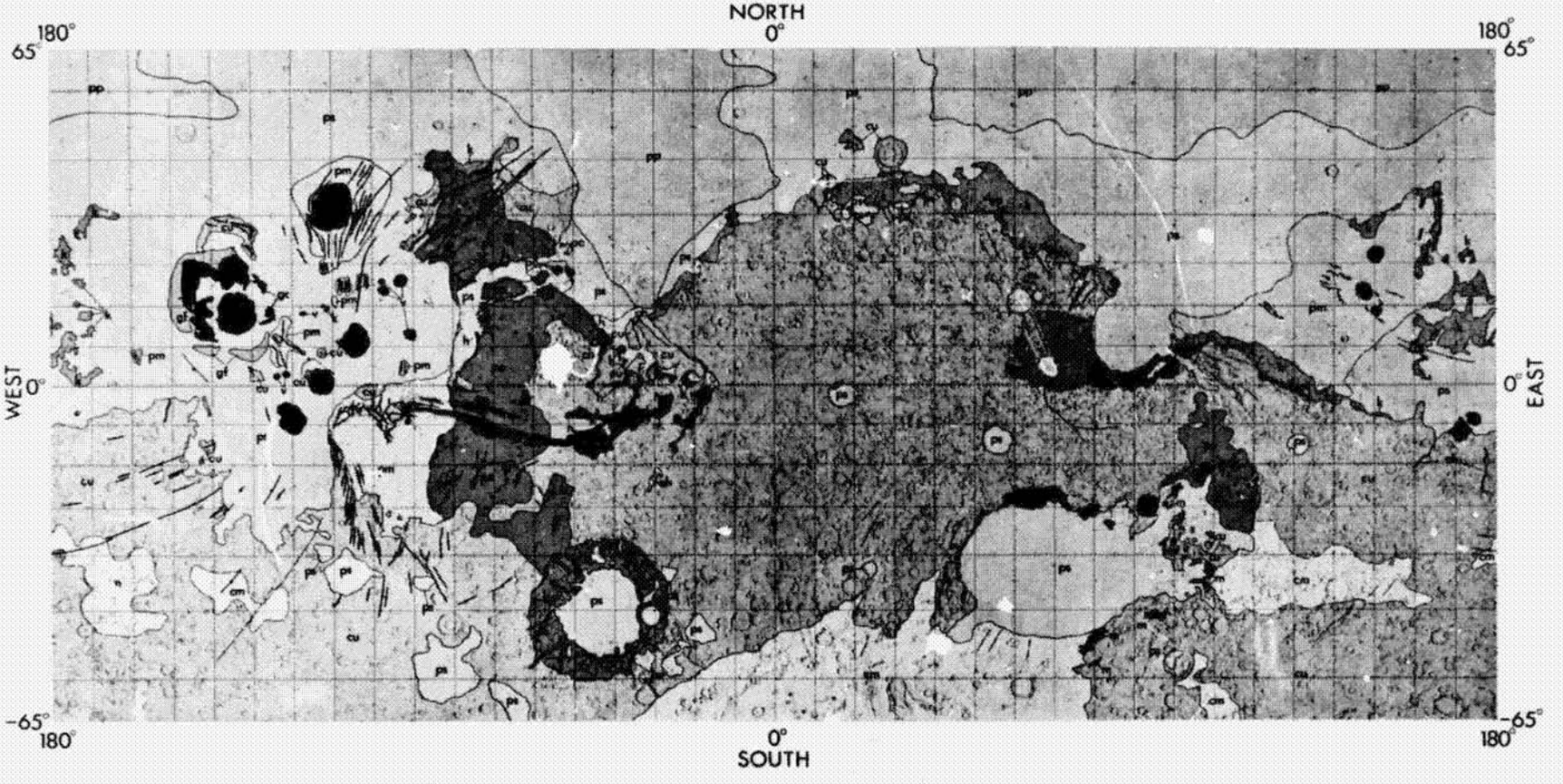

Fig. 1. Generalized geologic map of the region of Mars between 65°N and 65°S.

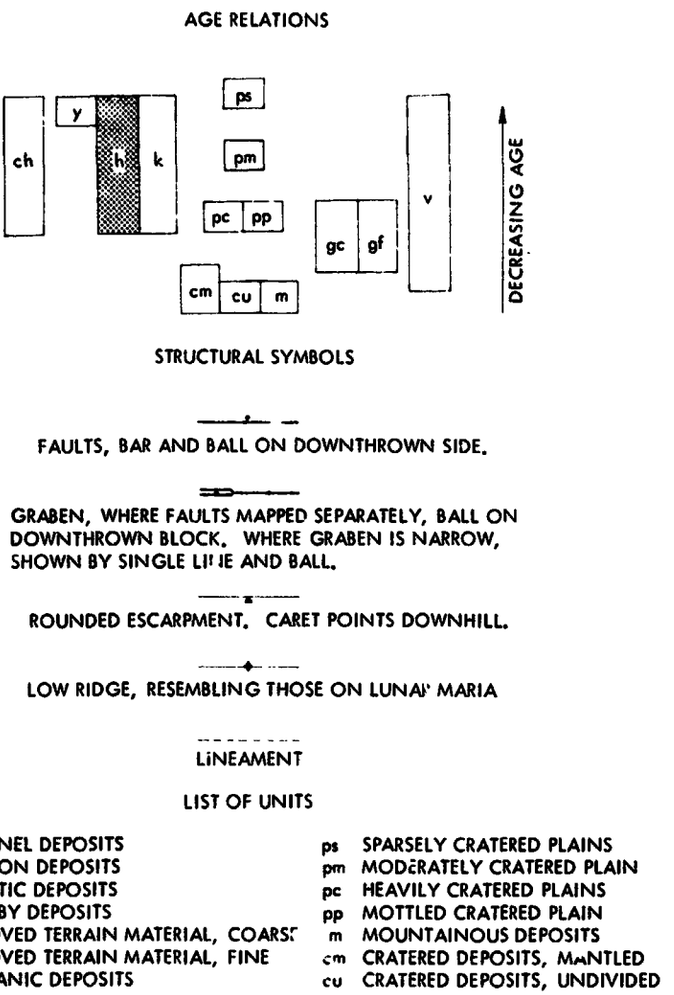

Fig. 2. Age relations and explanations of map symbols.

Description of Units

Densely Cratered Units

Densely cratered terrain covers approximately one half of the planet's surface, including most of the central and southern parts of the map and the south polar regions. The cratered area was photographed by Mariner 4, 6, and 7 in 1964 and 1969 and has been described in detail [*Murray et al.*, 1971]. The surface is almost saturated with large (>20 km) flat-floored craters; the density of smaller craters, which are mostly bowl shaped, falls short of saturation by a factor of 10. Several large ring structures resembling lunar basins occur within the densely cratered terrain [*Wilhelms*, 1973]. The character of the cratered terrain varies both locally and on a regional scale. Around the large impact basins, positive relief features are more common than elsewhere, providing the basis for discriminating a mountainous unit (m). In other areas the cratered terrain appears to be partly mantled, so that fewer intermediate and small (<20 km) craters are present and the larger craters appear subdued. A unit termed 'cratered deposits, mantled' (cm) has therefore been designated; the rest of the densely cratered deposits are left undivided (cu).

Cratered deposits, undivided (*cu*). This unit forms the primitive accretionary surface of the planet. It occurs primarily in the southern midlatitudes but extends to 40°N around the

330°W meridian. Isolated areas occur in the volcanic province. The unit is saturated with large flat-floored commonly rimless craters. Intercrater areas are flat and featureless except for scattered small bowl-shaped craters. Locally they may be partly covered by younger deposits, so that the topography has a muted appearance. Ridges, resembling those on the lunar maria, occur in some of the muted areas. The unit probably consists mostly of reworked impact breccias but locally includes younger volcanic and eolian deposits.

Cratered deposits, mantled (*cm*). This unit is mapped only where extensive areas appear mantled. Fewer intermediate and small craters (<20 km) occur than in unit cu. The unit occurs primarily in high southern latitudes and is interpreted as cratered deposits mantled by various thicknesses of younger material. Lobate flow fronts indicate volcanic materials in some areas, but the mantling material almost certainly includes significant portions of eolian debris.

Mountainous deposits (*m*). This unit forms the rugged parts of the rims of the three largest recognized impact basins, Argyre, Libya, and Hellas. Argyre (50°S, 43°W) is surrounded by rugged terrain cut by graben. The Libya basin (15°N, 270°W) rim is preserved as a distinct mountainous unit only at the south side of the basin. The Hellas (45°S, 295°W) rim is subdued. Mountainous terrain with relief comparable to Argyre is preserved only in isolated areas, particularly to the east where there is a complex array of isolated mountains. The mountainous unit is interpreted as remnants of parts of the primitive crust uplifted during the formation of the impact basins. Remnants of basin ejecta are also included.

Plains-Forming Materials

Plains, showing various degrees of cratering, occur over most of the planet not covered by the densely cratered units. The plains-forming materials are thought to be largely volcanic and eolian in origin. They have been divided into three units on the basis of the number and character of the superimposed craters.

Heavily cratered plains materials (*pc*). This unit is the most heavily cratered of the plains units but has fewer large craters than the densely cratered units described. It is equivalent to unit mc of *McCauley et al.* [1972] and occurs mainly in the areas north and south of Lunae Palus and in Hesperia. Ridges resembling those on the lunar maria are common. This material is interpreted as old lava plains similar to the lunar maria. (Small areas of material similar to this are present widely throughout the densely cratered area; they are not mapped because of scale limitations.)

Moderately cratered plains materials (*pm*). This unit has fewer craters in the size range 2–20 km than unit pc but more than unit ps [*Carr*, 1973]. It occurs in Elysium around the major shield volcanoes, in the Arcadia-Tharsis region, where it is exposed mainly as islands surrounded by unit ps, and in the region of Phoenicus Lacus. In the Arcadia-Tharsis region the unit is almost everywhere intensely fractured. It is interpreted as volcanic lava plains intermediate in age between units ps and pc.

Sparsely cratered plains materials (*ps*). This unit occurs mainly in the Amazonis-Tharsis region and in the large impact basins in the densely cratered province. Unit ps is the least cratered and presumably the youngest of the plains units. At wide-angle resolution it is relatively featureless, except in places close to its contact with the densely cratered terrain, where indistinct ridges and low rounded hills are common. At narrow-angle resolution irregular lobate scarps suggestive of flow fronts are common, especially in the Tharsis region. Low hills, islands of highly fractured terrain, sinuous channels, and polygonal fractures occur in other areas. More rarely, the narrow-angle pictures are featureless. In the Tharsis region the plains appear to be composed mainly of volcanic flows, since lobate flows are detectable on nearly all narrow-angle pictures. In the Amazonis region and in the large impact basins, Argyre, Hellas, and Libya, volcanic features are rare, and the eolian component probably dominates. The unit embays all other units, confirming the young age inferred from the crater counts.

Mottled cratered plains materials (*pp*). This unit occurs only at high northern latitudes where it forms an annulus around the pole. The density of large (>20 km) craters is comparable to that of unit pc, but the density of smaller craters is substantially lower. Large craters are subdued and apparent mainly because of an albedo contrast between the light crater floors and the dark surrounding materials. The local albedo

contrasts give the unit a mottled appearance. The albedo of the unit as a whole is lower than that of unit ps, with which it is generally in contact to the south. It is interpreted as cratered plains material (pc) overlain by a mantle of eolian debris.

Volcanic Units

Included under this heading are all volcanic units associated with roughly circular volcanic structures, as distinct from the extensive plains units. Because of limitations of scale, only two categories are depicted: a general unit v and another unit consisting of two facies (gc and gf), which form some very distinctive terrain around Nix Olympica.

Volcanic materials (*v*). This unit includes materials associated with shield volcanoes, volcanic domes, and volcanic craters (units vs, vd, and vc of *McCauley et al.* [1972]). Most of these features are circular and radially symmetric and have a central crater and gently sloping flanks. They occur primarily outside the densely cratered region, although two features within the densely cratered province are indicated on the map. The volcanic deposits have a wide range of ages. Those associated with Nix Olympica are relatively young [*Hartmann*, 1973]; those within the cratered province are relatively old [*Carr*, 1973].

Grooved terrain materials (*gf and gc*). Two facies of grooved terrain are recognized: a unit gc with a coarse surface topography that occurs close to Nix Olympica and a unit gf with a finer surface texture that occurs farther away. The coarse unit gc is characterized by linear mountains 1–5 km wide and typically 100 km long. The mountains are commonly separated by valleys that have flat floors with a fine striation parallel to the length of the valleys. The unit appears to be broken into blocks along arcuate faults that tilt the blocks gently inward toward Nix Olympica. The fine-textured unit gf is characterized by closely spaced equidimensional mountains whose horizontal and vertical dimensions decrease outward from Nix Olympica until the mountains merge with the surrounding plains. Both units are complex embayed by the surrounding plains deposits.

The grooved terrain deposits may represent old volcanic materials derived from the Nix Olympica center and since complexly fractured by the continual tectonic activity associated with the formation of the central shield. An alternative hypothesis is that the grooved terrain represents the outer remnants of a once much larger Nix Olympica that has been reduced in size by whatever process has formed the bounding scarp

Other Units

In several areas erosional and tectonic processes have resulted in the formation of distinctive geologic units. Four categories have been identified.

Channel deposits (*ch*). These have all the characteristics of terrestrial stream deposits. They occur in long, linear, sometimes sinuous channels that commonly have well-developed tributaries. Narrow-angle pictures show terraces, bars, finely braided networks of channels, and superimposed meanders. The most prominent channels head in the area of chaotic terrain around 2°N, 30°W and run northwest to the Chryse basin. Most, but not all, other channels occur in the densely cratered terrain near its contact with the plains. The unit is interpreted as materials deposited by a fluid, presumably water [*Milton*, 1973].

Canyon deposits (*y*). This unit includes materials that are exposed on the floor of the major rift system that extends 4000 km across the surface close to the equator between 30° and 100°W. The talus on the canyon walls is excluded. In most places the floor appears smooth, but locally jumbled blocks are present. At the eastern end of the canyon the unit merges with the chaotic terrain. At the western end the unit is pinched out as the canyon grades into a zone of branching troughs.

Chaotic deposits (*h*). Chaotic deposits have been described in detail previously [*Sharp et al.*, 1971]. The surface of the unit is crossed by numerous intersecting cracks that break the surface into blocks that have a wide range of sizes and that may be tilted slightly in different directions. The chaotic deposits normally occur in locally low areas, occasionally in completely closed basins. The outcrop areas are usually surrounded by an inward-facing scarp. The main area of occurrence is a broad region around 5°S latitude, 35°W longitude. The origin of the unit is obscure. Some process of sapping from below and subsequent collapse is required.

Knobby deposits (*k*). The unit is characterized

by irregular rounded hills and intervening plains. The hills are all sizes, from several hundred kilometers down to the limit of resolution (<1 km). The unit occurs mostly in a zone up to 500 km wide between the cratered terrain and the plains units. In general, the individual hills are larger and have more rectilinear outlines and flatter tops closer to the cratered terrain. Farther from the cratered terrain they become rounded and smaller in both horizontal and vertical dimensions until they merge with the surrounding plain. The unit includes the unit kt of *McCauley et al.* [1972] and the fretted terrain of *Sharp* [1973].

Structural Features

Mars is characterized by an abundance, if not a great variety, of structural features. The most common are graben, typically 1–5 km wide. They may occur as closely spaced parallel arrays, as in the Arcadia region, or as isolated fractures several thousand kilometers long, as in the Mare Sirenum region. The distribution of graben is markedly nonuniform. Most grabens are part of a system of faults approximately radial to the Tharsis ridge. The western part of the Coprates canyon also appears to be part of this set. The focal point of this vast system of fractures is the Phoenicus Lacus area, which is also the highest part of the ridge. The pattern appears to have formed as a result of the extension associated with the broad domical uplift of the Tharsis region.

Elsewhere fractures occur concentric and radial to the large impact basin of the densely cratered province [*Wilhelms*, 1973]. Fractures also occur locally around the large shield volcanoes [*Carr*, 1973] and at and parallel to the margin of the densely cratered terrain to form the knobby and fretted terrains [*Sharp*, 1973].

Mare ridges are the other common structural feature. They occur primarily on the most heavily cratered plains unit (pc). West of the Tharsis ridge they are aligned along directions concentric with the center of the Tharsis ridge.

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